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ABSTRACT

Designed to address major conceptual problems associated with heat and temperature, this module can be used with high school students or college nonscience majors including those in elementary education. The materials offer guidance to teachers in diagnosing student deficiencies, in creating dissatisfaction with misconceptions, and in providing opportunities for application and practice. This module contains: (1) an introductory section (discussing the misconceptions related to heat and temperature and how to use the module to overcome these barriers); (2) diagnostic test and commentary (designed to be used as a pretest and/or posttest); (3) materials for lecture or discussion (consisting of a series of copy-ready masters for use as overhead transparencies and student handouts on the topics of heat transfer, states and phases of matter and methods of heat transfer); (4) laboratory activities/demonstrations (including lessons on heat and temperature, heat capacity, and heat transfer through radiation); and (5) problem sets and commentary (presenting problems dealing with heat and temperature and methods of heat transfer). (ML)

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HEAT AND TEMPERATURE: A TEACHING MODULE

Robert E. Hollon and Charles W. Anderson

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Robert E. Hollon and Charles W. Anderson

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Abstract

This module is one in a series developed by the project Overcoming Critical Barriers to Learning in Nonmajors' Science Courses. Each module is self-contained and addresses a specific topic in the physical and biological sciences: respiration and photosynthesis, evolution by natural selection, light, and ecology. The modules are appropriate for use with high school students or college nonscience majors including those in elementary education.

This module on heat and temperature is arranged with materials for the instructor on one page juxtaposed by those for the students. A short introductory essay describes the major conceptual problems found among students: Distinguishing between heat and temperature, between heat and other forms of energy, and using kinetic energy of heat to explain observable phenomena. It then explains how activities in the unit are intended to help students overcome these problems.

A diagnostic test, which could be used as a pretest, posttest, or both, is designed to reveal important student misconceptions and provides notes for the instructor to intepret student responses. A set of student handouts and masters for overhead transparencies includes notes for the instructor about conceptual problems each was designed to address. Laboratory activites on heat and temperature, heat capacity, and heat transfer through radiation are followed by problem sets on (a) heat and temperature and (b) methods of heat transfer designed to address specific student misconceptions.

The first three parts can be used independently or in combination with the laboratory activities and problem sets after students have learned the relevant concepts. The materials help instructors accomplish three tasks essential to overcoming critical barriers to student learning: diagnosing student deficiencies, creating dissatisfaction with misconceptions, and providing opportunity for application and practice.

About the Authors

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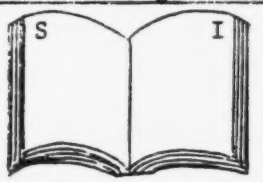

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Preface

We hope that using this module will help you gain insight into your students' understanding, and misunderstanding, of heat and temperature. One of its main purposes is to provide opportunities for you to learn about your students' thinking. Because of what you discover about their thinking, you may have to move more slowly and cover less content than you would like. That may seem like a problem, but we don't think so. It is far better to have students learn to understand a little science than to have them misunderstand a lot.

I. Introduction

Purposes of this Module

Which of the following are forms of energy: Temperature, heat, cold, light?

What happens to the molecules in ice when it melts?

How can the sun warm the earth across 93,000,000 miles of vacuum?

Each of these questions reveals something important about how students understand heat and heat-related phenomena. How would your students answer them? Would you be satisfied with their answers?

It is the purpose of this module to help students reach the point where they can provide satisfactory answers to questions like those above. The module is designed to promote student understanding in three related areas:

1. Distinguishing between heat and temperature.

2. Understanding the relationship between heat and other forms of energy, especially as revealed in heat transfer processes and changes of state.

3. Understanding the kinetic theory of heat at the molecular level and its relationship to observable heat-related phenomena.

Although we regard these ideas as relatively simple and elementary today, they were not achieved early or easily in the history of science. Newton and his contemporaries failed to achieve a modern understanding in any of the above areas. The first theory of heat which clearly distinguished between heat and temperature was formulated by Joseph Black, who studied heat capacity and the latent heat of fusion in the late eighteenth century. A modern understanding of the relationship between heat and other forms of energy was achieved even later. It was not until the 1840's that the caloric theory of heat was finally rejected in favor of the kinetic theory, and that a theory of energy that clearly explained the relationship between heat and other forms of energy was formulated by Helmholtz and others.

This historical review is relevant because the ideas that were rejected by Black and Helmholtz did not dic in the 19th century. They remain alive today in the minds of our students, who must confront many of the same sources of confusion about heat-related phenomena as 18th and 19th century scientists. Some of those sources of confusion remain today as critical barriers to the understanding of heat.

Critical Barriers to Understanding Heat and Temperature

How can we best help students to learn these fundamental concepts? A reasonable answer seems to be that students will learn science if the scientific content is presented in a logical, well-organized manner. However, anyone who has ever taught science knows that teaching and learning science is just not that simple. Students often seem unable to comprehend the most

simple, logical presentations. They resort to memorizing facts instead of trying to understand concepts. Why? What keeps them from comprehending explanations which are based on scientific thought?

Extensive research comparing inexperienced students with scientific experts as they think about scientific problems shows that the students think and act in ways that make sense to them, but which are not compatible with scientific thought. For example, many students believe that a small amount of hot water contains more heat than a large amount of cool water. Their belief makes sense in terms of their experience, since they habitually think that hot things contain heat and cool things don't. This habit of thought, or misconception, about the nature of heat and temperature prevents them from truly understanding the question, much less providing a scientifically meaningful answer to it.

The presence of these misconceptions makes the learning of science a far more complicated process than we normally imagine. Students cannot simply absorb or memorize scientific content. They must reassess and restructure their intuitive knowledge of the world. Furthermore, they must abandon misconceptions that have served them well all their lives in favor of new and unfamiliar ideas.

Misconceptions can be extremely resistant to change through instruction. They often persist even after students have apparently learned the scientific alternatives. Many students become adept at learning what is necessary to pass a science test while continuing to use their old ideas in "real world" situations. We have adopted a phrase from David Hawkins and describe these enduring habits of thought that interfere with scientific thinking as "critical barriers" to the learning of science.

In this module we have tried to identify the critical barriers that prevent students in a non-majors' physical science course from understanding heat concepts. In addition, we have tried to develop teaching materials which will address these barriers and help students to overcome them. The module is based on extensive investigations of how students think about heat and temperature, and heat transfer processes. We have administered diagnostic tests to several hundred students, both before and after instruction, and analyzed their performance. We have conducted in-depth interviews with some of the students to assess their understanding of heat concepts, and to validate our diagnostic procedures. Several professors and laboratory instructors have field-tested the materials in our own course. The result, we believe, is a set of materials that teachers can use to help scientifically inexperienced students take the first steps toward a mature scientific understanding of heat.

Distinguishing between heat and temperature. The caloric theory of heat was discredited during the nineteenth century, thus it is easy to ignore what a major intellectual advance it represented. Rather than simply observing the conditions that made objects warmer or colder, scientists for the first time explained temperature changes in terms of an unobservable mechanism: the movement of an invisible caloric fluid. In the process, they distinguished between heat (the amount of caloric fluid) and temperature (the concentration of that fluid).

Each of these insights remains incorporated in current theories of heat. Although they no longer think about caloric fluid, physicists still distinguish between heat and temperature, and in many instances still use the phrase "heat flow." The movements and transformations of *energy*, another sort of invisible quantity that is always conserved, also play an essential role in understanding of heat-related phenomena.

An appreciation of these insights is important because most beginning physics students are very much in a precaloric state of understanding. They see and feel temperature changes and their effects, but they rarely invoke heat flow as a mechanism to explain those changes.

Most students in our nonmajors' physical science course have never completed a high school chemistry or physics course. Their last exposure to scientific heat and temperature concepts may have been in junior high school. As a result, they have developed commonsense theories to explain familiar experiences with heat phenomona. These commonsense theories serve the students reasonably well in their day-to-day existence, but are scientifically inadequate or incomplete, and incorrect.

The following examples illustrate students' naive conceptions about the nature of heat and temperature. They are typical responses to a question on the diagnostic test used in this module.

A cup contains water at 30° C, and a bathtub contains water at 10° C. Which contains more heat?

--"The cup because it is hotter."

--"The cup. 30° is bigger than 10."

--"The cup because it has a smaller volume."

--"The cup because it's more concentrated."

These responses suggest that students do not always distinquish between heat and temperature. Instead, they treat heat and temperature as synonymous words that label a single concept. We call this concept "hotness." It has some of the qualities that physicists associate with both heat and temperature. In the example above, many students reason that the hotter object must contain more heat (i.e., "hotness").

Another section of the diagnostic includes a diagram of a metal rod being heated at one end by a bunsen burner:

If the rod is heated at end A, end B will also become hot. Explain.

--"When you heat one end, the whole thing heats up."

--"The hot molecules move to end "B", making it get hot."

--"Because the hot end causes the rest of the rod to heat up."

--"Because metal conducts the temperature."

Although the students attempt explanations for heat transfer, the explanations tend to be reflections of their experience with temperature. In struggling to construct a plausible explanation, they rely on temperature or "hotness", because they have no alternative.

Heat and other forms of energy. Most students do not exhibit a commitment to conservation of energy in thinking about everyday life. They see examples of energy appearing and disappearing all the time: Sound and light are absorbed or dissipated; rocks fall to the ground and stop moving; cars move without any external force; temperatures rise and fall. For these students, it is a major intellectual accomplishment to realize that energy (in all its various forms) is in fact conserved in these systems. It is even more difficult for them to learn how to trace the path taken by the energy as it changes both form and location. And yet, this form of reasoning is absolutely basic to modern physical and biological science.

Problems involving heat flow and heat transfer play an essential role in developing the ability to treat energy as a conserved substance, for heat plays an essential role in a great many interactions, especially those where other forms of energy (such as light, sound, or motion) seem to simply appear or disappear. Thus, learning to follow heat flow, rather than simply describing temperature change, is an essential step in achieving an understanding of the central role that energy plays in modern science.

Using the kinetic theory of heat to explain observable phenomena. Part of the appeal of the caloric theory of heat lies in its simplicity. Heat often *seems* to act like a fluid that flows from one place to another, so why not say that is *is* a fluid? The reason, of course, is that we are now convinced that it is not true; heat consists solely of the kinetic energy of the molecules of a substance.[1]

Although the basic idea is easily stated, understanding its implications is very difficult for most students. They must learn that molecules possess some of the properties of objects that they are familiar with (such as mass and velocity) but not other properties (such as color and temperature). They must learn to explain phenomena such as temperature, heat transfer, and changes of state as observable manifestations of quite different processes happening at the molecular level.

Initially, most students are unable to do this. When they are asked to give molecular level explanations of observable phenomena, they often find themselves unable to say anything at all. Those who do attempt answers often try to discribe the molecules as undergoing the same processes as observable objects (for instance, describing molecules themselves as melting, freezing, or getting hotter).

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[1]The model of heat developed in this module does not consider rotational or vibrational energy states of molecules. Thus no distinction is made between heat and internal energy or thermal energy, and no attempt is made to explain why different substances have different heat capacities.

The diagnostic question about heating the metal rod also asks students to explain what the bunsen burner is doing to the atoms in the rod:

"The atoms are getting hotter and expanding."

"They are enlarging."

"The heat flows through the atoms and excites them, making them get bigger."

"The heat makes the molecules want to expand."

The students realize that the heat from the bunsen burner causes the rod to expand. However, because they don't think about heat as molecular motion, the only explanations they can propose are those which transfer observable effects of heating to individual molecules.

Summary tables. The issues discussed above are summarized in the following tables. For each issue we contrast a goal conception, describing the understanding that we would like students to achieve, with a naive conception, describing ideas commonly held by students in our physical science course.

Table 1

Nonmolecular Explanations of Heat-Related Phenomena

Issue	Goal Conception	Naive Conception
Nature of heat	Heat is a form of energy. It is an extensive quantity which cannot be measured directly.	Heat and temperature are not clearly distinguished. Students use both terms to refer to a single concept (hotness) with both extensive and intensive properties.
Nature of temperature	Temperature is an intensive property of matter which can be measured directly.	
Meaning of absolute zero	All heat is lost from a substance only at -273° C.	Cold or frozen objects have lost all heat (hotness).
Heat transfer	Heat is transferred via conduction, convection, or radiation.	Hot objects simply cause cold objects to get warmer.
Conservation of energy	Changes in temperature must involve transfer of heat energy.	Objects simply become hotter or colder in response to their surroundings.

Table 2

Molecular Explanations of Heat-Related Phenomena

Issue	Goal Conception	Naive Conception
Nature of heat	Heat is the total kinetic energy of the molecules of a substance.	Individual molecules contain heat.
Nature of temperature	Temperature is the average kinetic energy of the molecules of a substance.	Molecules are hot or cold (transfer of macroscopic properties to molecular level).
Heat transfer	Conduction is the transfer of kinetic energy via collisions between molecules. Convection is the transfer of energy due to the movement of groups of fast-moving molecules. Radiation involves the transformation of the energy of electromagnetic radiation into molecular motion, and vice versa.	Hot objects simply cause cold objects to get warmer. (Students do not propose molecular level mechanisms.)
Thermal expansion	Speed and distance between molecules varies with temperature.	Individual molecules expand when heated.
Phases of matter	Phase depends on balance between kinetic energy of molecules and intermolecular forces.	Individual molecules somehow change states themselves.

Using this Module to Overcome Critical Barriers

For many students in a beginning physical science course, the naive conceptions described above are deeply ingrained. We have found that for such students even the best explanations are not enough. Replacing easy and familiar naive conceptions with more scientifically correct conceptions is a difficult process, requiring sustained effort on the part of the student, corrective feedback from teachers, and many opportunities for practice and application.

The materials in this module are ones that we have developed, field tested, and found to be useful in helping students to overcome the critical barriers described above. In addition to lecture materials providing clear explanations of heat, temperature, and heat transfer processes (Section III), this module includes a diagnostic test that can be used as both a pretest and a posttest (Section II), laboratory activities (Section IV), and problem sets (Section V). The materials can be used either independently or in combination, and they do not need to be used in any particular order, although the laboratory activities and problem sets are designed to be done *after* students have read or heard explanations of the relevant concepts. The materials are useful because they help teachers do three things that are essential for helping students to overcome critical barriers:

1. Diagnose of student difficulties. The diagnostic test, the laboratory activities, and the problem set all contain questions designed to reveal how well students understand heat and temperature. The commentary for teachers describes specifically what each question is designed to reveal.

2. Create dissatisfaction with naive conceptions. Many students enter our course expecting to memorize facts and definitions when we would like them to think scientifically. The activities in this module provide students with many opportunities to see that their present ways of explaining and predicting scientific phenomena do not work very well and to understand how their ideas need to be improved.

3. Provide opportunities for practice and application. The scientific conceptions described above are important because they explain many different phenomena in a satisfying way. The activities in this module help students to see the power of these conceptions by applying them to a variety of phenomena. Since the basic purposes of scientific theories are to explain and to predict, we feel that the questions asking students for explanations and predictions are especially important.

In short, the questions and activities in this module are designed as tools to help you, the instructor, help your students through the process of conceptual change. This module cannot substitute for your personal planning and judgment, but can help you make your plans and judgments better informed and thus more effective.

II. Diagnostic Test and Commentary

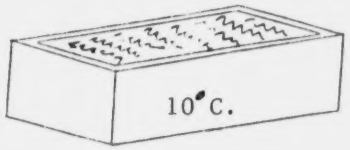
This student test has been developed and tested over the course of several terms. It is designed to be given as a pretest and/or posttest. It should take about 15 minutes for most students to complete. As a pretest, it is designed to help you (a) assess your students' background in subjects critical to an understanding of heat and temperature and (b) become aware of the critical barriers to student learning when they enter the class. As a posttest it gives you an opportunity to evaluate the success of your teaching.

The following left-hand pages contain the test as we have used it with our students. The right-hand pages contain a commentary explaining the purposes of each question and how students answers can be interpreted.

Your students' answers will probably be most revealing and useful if students do not take the test for a grade and if you ask them to try to describe how they think about the problem even when they do not know the correct scientific answer. The students' incorrect answers to these questions are often more interesting and revealing than their correct ones.

Heat and Temperature

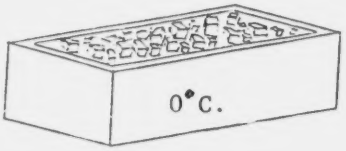
1. A cup contains water at 30° C and the bathtub contains water at 10° C, as shown in the diagram below.



   a. Which contains more heat?_____

   b. Explain your answer.

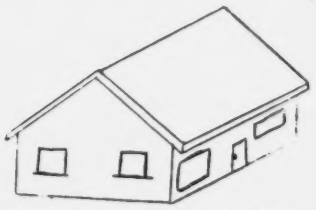
2. A cup contains water at 30° C and a bathtub contains ice at 0° C; as shown in the diagram below.



   a. Which contains more heat?_____

   b. Explain your answer.

3. The diagram at the right shows a house on a winter day. The furnace is turned off and the temperature inside the house begins to drop.



   a. Which of the following describe(s) what is happening:

      1. The house is losing heat

      2. Cold is seeping into the house

      3. Both processes are occurring

   b. Explain your answer.

Commentary

1 & 2.

These questions are designed to probe students' understanding of the difference between heat and temperature. We believe that the best responses to these questions should identify heat as the total kinetic energy of the molecules and relate the quantity of heat to the number of molecules in each vessel.

Students who choose the tub in both questions probably understand that the quantity of heat in a substance is related to the amount of matter present as well as the temperature. However, they may or may not define heat as the total kinetic energy of the molecules.

Students who choose the tub in Question 1, but the cup in Question 2 may be partially committed to the relationship between heat and mass, but are confused about the heat content of objects in different phases. Phrases such as "the heat is lower because it's ice," or "things at 0° have lost all their heat," or "ice doesn't have any heat in it" are indicators of this sort of confusion.

Students who choose the cup in both questions almost invariably are confusing heat and temperature. Their explanations will include phrases such as "30° is greater than 0°," "the cup because it's hotter," or "the heat in the cup is more concentrated." Their explanations focus on temperature-related properties of the system.

3 & 4.

These questions probe students' understanding of the nature of heat, and the processes by which heat is transferred. Students who understand that heat exists as a form of energy but cold does not will choose answer "1" for Questions 3a and 4c. They will also indicate that the temperature of the cube will rise and that the temperature of the water will fall. Their explanations will include phrases such as "the heat flows from hot to cold," or "heat gets transferred from hot to cold." Students who use "heat flow" probably understand that heat and temperature are not the same, but do not think of heat in terms of the motion of molecules.

Students who indicate that cold is seeping into the house or that both processes are occurring may be thinking about cold air in the form of draft or leaks around windows and doors. However, they may also have a bipolar conception of heat, viewing the cold as "something" which can get into the house and counteract the heat. Comparing responses to 3b and 4d will provide a better indication of the students' conceptions.

These questions also provide some information about students' understanding of the interaction between hot and cold objects. Students who recognize that the temperature of the cube will increase but don't recognize that the temperature of the water also decreases probably are not thinking about energy being transferred or conserved.

4. A metal cube at 0° C is dropped into a container of water at 20° C, as shown in the diagram at the right.

   a. Will the temperature of the metal cube rise or fall?_____

   b. Will the temperature of the water rise or fall?_____

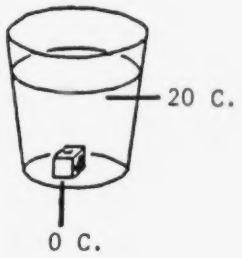
   c. Which of the following explains what is happening?

      1. Heat is transferred from the water to the cube.

      2. Cold is transferred from the cube to the water.

      3. Both processes are occurring.

   d. Explain your answer.



5. A person is standing outdoors on a bright sunny day. Explain how the sun, which is 93 million miles away, makes the person's skin warmer.

6. Which of the following is/are forms of energy? (circle all correct)

   Temperature Heat Cold Light Gasoline

7. Why does the level of the liquid in a thermometer rise when the thermometer is heated? Explain.

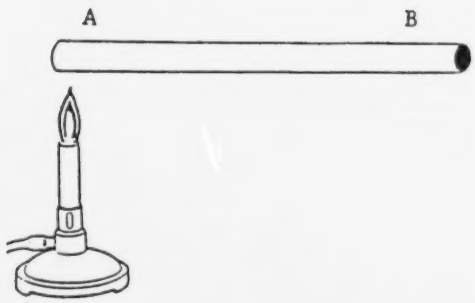
5. Question 5 probes students understanding of energy transfer via radiation. Students who understand that radiation and heat are not the same will include phrases that refer to radiation (or light or electromagnetic radiation) being *converted* into heat when it reaches the earth. They may describe the conversion in terms of the radiation increasing the kinetic energy of the molecules in the skin.

   Students who don't understand this process usually don't regard radiation and heat as separate forms of energy which are related through a conversion process. They will refer to "the heat contained in the light," or "the sun giving off heat and light" (not recognizing that heat can't travel through space). Some will use a cause-effect explanation, such as, "the sun makes your skin hot" or "the sun increases the temperature of the earth" without describing any transfer process at all.

6. Question 6 probes students understanding of the different forms of energy. Although most students realize that heat is a form of energy, at least 50% also choose cold and/or temperature. These students clearly have not differentiated heat from temperature and do not understand the nature of heat.

7. Question 7 enables the instructor to assess the students' conceptions about the effects of heating matter. Students who understand thermal expansion will describe the rise of the mercury in terms of the liquid expanding. Some will provide a molecular-level explanation which describes the "molecules getting further apart," or "moving apart because they're moving faster and have more kinetic energy."

   Students who do not understand thermal expansion typically respond using a "heat rises" or "hot things rise" explanation. Students often incorrectly transfer macroscopic properties to the molecular level, referring to individual molecules expanding or hot molecules rising.



8. a. The length of the iron rod in the above diagram is measured and found to be 22.000 cm at room temperature. The rod is then heated for 15 minutes and its length is measured again. The length of the heated rod should be:

   1. more than 22.000 cm
   2. still 22.000 cm
   3. less than 22.000 cm
   4. It depends on how much the temperature of the rod rises
   5. I don't know

   b. What do you think the bunsen burner is doing to the atoms of iron in the rod that could explain your answer to part a, above?

   c. If the rod is heated at end A, end B will also become hot. Explain how you think this happens.

9. Explain or draw pictures to show the difference in molecules or their arrangement for the following:

   a. ice

   b. liquid water

   c. water vapor

10. Do you think that there is any difference between heat and temperature?_____
    If so, explain the difference.

8. Question 8 provides further evidence of the students' conceptions of the effects of heating matter, and their understanding of conduction. Students with a goal conception should choose Answer #1 under 8a. Their explanation in 8b should refer to the heat increasing the kinetic energy or motion of individual atoms, causing them to move further apart. In part c, they should identify the heat transfer process as conduction, and describe the transfer of energy in terms of collisions between adjacent atoms.

   Some students may answer Question 8c using phrases such as "heat flows" or "heat moves" through the rod. Again, these students don't think of heat in terms of molecular motion, although they probably differentiate heat from temperature.

   Students with a naive conception of the effects of heating matter may still choose #1 under 8a as the correct response, but will refer to changes in the individual atoms (the atoms get hotter and atoms expand), and explain conduction in terms of hot atoms moving. Some may describe the result of heating without addressing any heat transfer process. They typically use phrases like " when you heat the rod at A, the whole thing gets hot."

9. Question 9 probes students' conceptions of the molecular nature of matter. We have found that many students realize that intermolecular distances increase with temperature, but few relate the increase in distance to increased kinetic energy or motion of the molecules. Some students understand that ice has a definite crystal structure, but are generally unaware of the existence or role of intermolecular forces in any of the phases of matter. In addition, many students assume that ice molecules do not move, or that ice molecules are somehow different from liquid and vapor molecules.

10. This question asks students to compare their concepts of heat and temperature. Good answers should make it clear that heat is an extensive quantity (it refers to the total amount of something) while temperature is intensive (it refers to concentration). Some students will probably fail to make this basic distinction.

    Other students may make the distinction but be unable to explain it on the molecular level; they will fail to describe the connection between heat, temperature, and molecular kinetic energy.

III. Materials for Lecture or Discussion

This section contains a series of copy-ready masters for use as overhead transparencies and student hand-outs.

1. The overhead transparencies may be used as lecture supplements, or as a basis for discussion in lectures or recitations.

2. The student handouts may be discussed in lecture or recitation or used by the students as study guides.

Each sheet is designed to address one or more key concepts and/or to confront important critical barriers. They are found in copy-ready form on the left page, with an explanation of the purpose of the sheet on the right page.

Contents

Heat and Temperature--student handout (page 14)
Methods of Heat Transfer--student handout (page 15)
Heating the Earth--overhead transparency (page 16)
Heat and States of Matter--overhead transparency (page 17)
Phases of Matter--overhead transparency (page 18)
Changes of State--overhead transparency (page 19)

Heat and Temperature

1. What is heat?

Heat is a form of energy. It is the kinetic energy that molecules have because they are moving. The phrase "How much heat" refers to the total amount of kinetic energy in all the molecules throughout the system. This means that the amount of substance (mass) is an important factor.

Misconceptions about Heat and Temperature

Heat is not a substance or matter. It does not flow between molecules like water flowing around rocks in a stream. However, physicists often speak of heat transfer or heat flow when the molecules of a substance gain or lose kinetic energy. Note that individual molecules do not contain heat. They contain kinetic energy because they are moving or vibrating.

2. What is temperature?

Temperature is the average kinetic energy of the molecules in a system. It lets us compare the kinetic energy of molecules in one system to the kinetic energy of molecules in another system. If we touch a stove and say it is hot, we really are saying that the average kinetic energy of the molecules in the stove is higher than the average kinetic energy of the molecules in our fingers.

Temperature is not energy, nor is it the same as heat. Temperature does not tell us how much heat a system contains. It provides us with information about the motion of the molecules but tells us nothing about the number of molecules in the system. Notice that the terms "hot" and "cold" generally refer to temperature, not heat. Molecules do not get hot or cold. They gain or lose kinetic energy.

3. What does the phrase "heat up some water" really mean?

Physicists interpret this phrase to mean that heat energy is somehow being transferred into the water. Its molecules are moving faster or gaining kinetic energy.

Note that the physicist emphasizes the transfer of heat energy into the system. Physicists attempt to explain all observed temperature changes in terms of energy transfer from one substance or place to another.

4. What does the phrase "chill some water" really mean?

Physicists interpret this phrase to mean that heat energy is being transferred out of the water. Its molecules are moving slower or losing kinetic energy.

"Cold" is not being transferred into the water. It is not a substance that is the opposite of heat. "Cold" is only a word that we use to compare the temperature of two objects.

5. When has an object "lost all its heat"?

Objects contain no heat only when the molecules lose all their available kinetic energy. This happens at Kelvin (-273° C).

Objects which are frozen, or at 0° C, still contain much heat even though they are cold. Their molecules must still lose a great deal of kinetic energy before their temperature drops to absolute zero.

Commentary

Heat and temperature are the two most fundamental concepts in the domain of heat. Many students, however, do not realize that heat and temperature are separate ideas. They tend to use both terms as if they were synonyms for "hotness," a concept which includes both the extensive aspects of heat and the intensive aspects of temperature.

This handout sheet confronts students' naive conceptions about heat and temperature by making explicit the differences between heat and temperature, and contrasting the scientific conceptions with common naive conceptions.

Methods of Heat Transfer

1. What do we mean by the term "heat transfer?"

Heat transfer refers to the process by which heat energy gets from one place to another. Heat transfer takes place via conduction, convection, or radiation. The energy is transferred from a body with a higher temperature to a body with a lower temperature.

Misconceptions about Heat Transfer

Heat transfer does not include creating heat energy from some other form of energy such as light. Scientists use the term "heat flow," but heat does not flow like water or any other fluid.

2. What do we mean by the term "energy conservation?"

To the scientist, energy conservation means that the amount of energy lost in one part of a system must be equal to the amount of energy gained in other parts of the system. For example, when an ice cube is placed in a glass of warm water, the heat that is transferred out of the water is equal to the amount of heat absorbed by the ice cube and the glass.

Energy doesn't just disappear. When an object becomes warmer or cooler some energy transfer must be taking place. The earth, for example, cools off at night by losing energy into space. Energy conservation does not refer to temperature. It is incorrect to say that "if one object gets 10° cooler, the other must get 10° warmer.

3. How is heat transferred by conduction?

Conduction occurs primarily in solids. The kinetic energy of the molecules is transferred as the vibrating molecules collide with one another. In this way, energy can be moved from one point to another, even though the molecules themselves are not free to move.

The molecules vibrate, but do not move from place to place. Collision only between adjacent molecules.

4. How is heat tranferred by convection?

Convection occurs in fluids (liquids and gases). When some portion of a fluid is heated, the faster moving molecules move further apart from one another. Since the colder portion of the fluid is denser, it sinks to the bottom of the container, gradually forcing the hotter, lighter fluid to the top. In convection, the molecules actually move from place to place.

It is incorrect to say that "heat rises." However, groups of hotter molecules will rise because they are less dense than groups of colder molecules.

5. How is heat transferred by radiation?

Radiation, unlike conduction and convection, does not involve molecules in in the actual transfer process. Hot objects emit energy in the form of electromagnetic waves which radiate through space until they are absorbed by molecules. The waves' energy is then transformed into kinetic energy in the molecules.

Electromagnetic rays such as light rays do not contain heat. They are a different form of energy which is transformed into heat energy only when the rays strike the molecules.

Commentary

Many students who recognize heat as a form of energy are confused about the processes by which heat is transferred from one body to another. Their confusion is compounded by terms like "heat flow" and "movement of heat" which are commonly used by physicists to describe the transfer of heat energy. Students who view heat as being capable of moving or flowing through a body may never completely abandon the naive conception that heat is a "fluid." Thus, they are not apt to fully understand the kinetic-molecular explanation of heat and heat transfer.

This handout confronts students' misconceptions about heat transfer processes by contrasting the kinetic-molecular explanations of conduction, convection, and radiation with common naive conceptions about them.

HEATING THE EARTH

1. THE EARTH IS HEATED BY THE SUN AND LOSES HEAT BACK INTO SPACE. THE ONLY WAY THE EARTH CAN GAIN OR LOSE HEAT IS

   _____

   (CONDUCTION, CONVECTION, OR RADIATION).

2. WHY ARE THE OTHER TWO WAYS IMPOSSIBLE?

3. WHAT TRAVELS FROM THE SUN TO THE EARTH THAT MAKES IT WARMER?

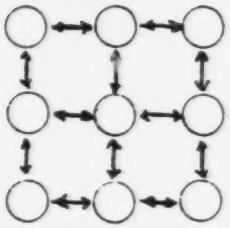
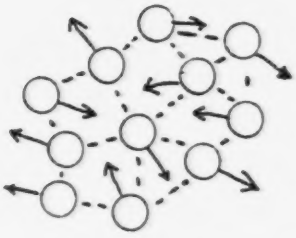
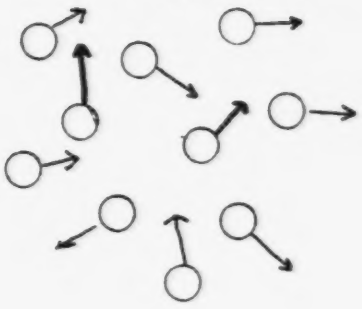
Commentary

This overhead transparency can be used as a quiz or discussion questions to assess students' ability to distinguish among conduction, convection, and radiation and their understanding of the conditions under which heat transfer by each method takes place. The final question checks to see whether students distinguish between light or electromagnetic radiation (which does travel through space), and heat (which does not).

1-2. Responses should indicate that radiation is the only process by which the earth can gain or lose heat, since the other methods require molecules, which aren't present in sufficient quantities in space.

3. The students should realize that light or electromagnetic radiation, which is a different form of energy than heat, is what travels from the sun to the earth. They should also realize that heat is not a part of the light.

HEAT AND STATES OF MATTER

STATE	DESCRIPTION	NATURE OF HEAT
SOLID 	EACH MOLECULE IS HELD IN PLACE BY INTER-MOLECULAR FORCES.	MOLECULES VIBRATE IN THEIR PLACES.
LIQUID 	MOLECULES MOVE AROUND, BUT ARE HELD CLOSELY TOGETHER BY INTERMOLECULAR FORCES.	ENERGY OF MOLECULAR MOTION THROUGH SPACE.
GAS 	MOLECULES TRAVEL FREELY, BOUNCING APART IF THEY COLLIDE.	ENERGY OF MOLECULAR MOTION THROUGH SPACE.

Commentary

This overhead transparency summarizes the relationship between heat and the phases of matter. Although many students are aware that molecules in gases and liquids are farther apart than molecules of solids, few relate distance to the movement of the molecules. Many students are unaware that molecules in solids are actually moving, and that intermolecular forces act between the molecules in solids and liquids.

PHASES OF MATTER

1. EXPLAIN IN TERMS OF MOLECULES AND THEIR MOTIONS WHAT THE DIFFERENCES ARE BETWEEN A SOLID (SUCH AS ICE), A LIQUID (SUCH AS WATER) AND A GAS (SUCH AS WATER VAPOR). DRAW PICTURES IF IT HELPS.

2. EXPLAIN WHAT IS GOING ON WHEN ICE MELTS. HOW DOES HEAT AFFECT THE MOLECULES OF THE ICE?

Commentary

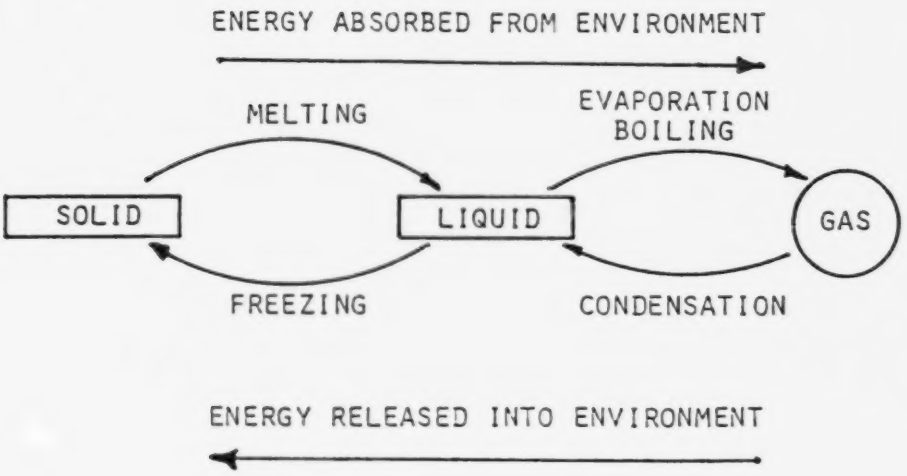
This overhead transparency is designed to help you teach students about the structure of matter and phase changes. It can be used as a short quiz or to stimulate class discussion.

Students tend to explain phase changes in terms of the distance between molecules, the speed of the molecules, or some combination of the two ideas. Some students explain phase changes in terms of the individual molecules, so that liquid water molecules are fundamentally different from ice molecules and water vapor molecules. Few, if any students consider the forces acting between molecules that result in some definite arrangement or crystal structure, nor do they associate phase changes with changes in the kinetic energy of the molecules.

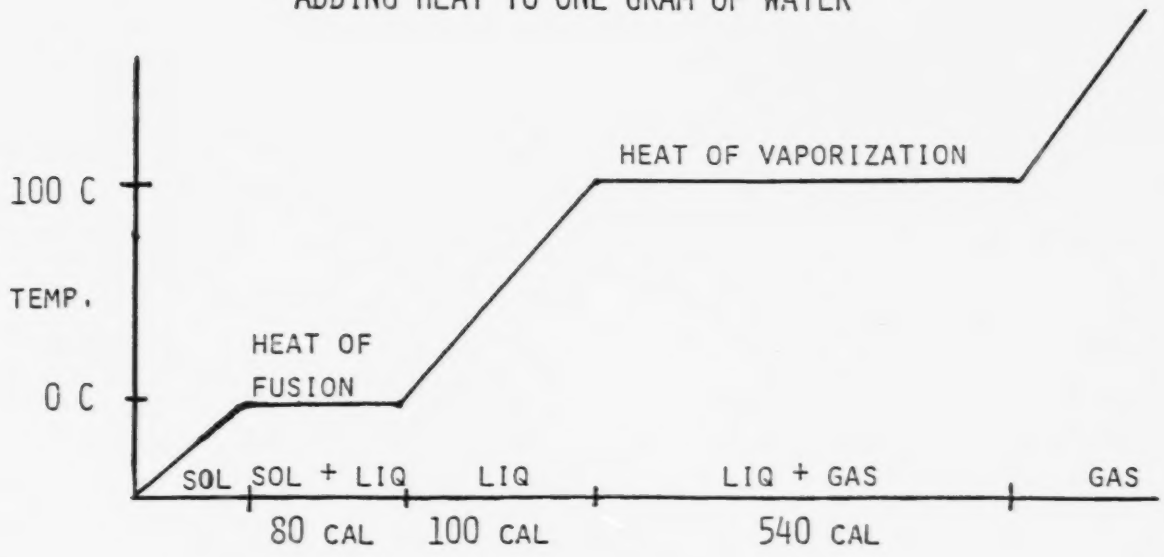
1. Responses to this question should refer to a definite molecular structure for ice, which breaks down as it gets warmer, should indicate increasing speed, increasing randomness of motion, and increasing distance between molecules.

2. Responses to this question should indicate that the molecules in the ice move faster as it is heated. The increased motion causes the crystal structure to break, allowing the molecules to move in a random fashion. Some students may refer to "ice molecules" changing to "water molecules."

CHANGES OF STATE



ADDING HEAT TO ONE GRAM OF WATER



AMOUNT OF HEAT ADDED

INCREASED PRESSURE <u>RAISES</u> THE BOILING POINT

INCREASED PRESSURE <u>RAISES</u> THE FREEZING POINT (EXCEPT FOR WATER)

Commentary

This overhead transparency summarizes the three phases of matter and identifies the processes by which matter changes from one phase to another. Many students are aware that substances change phase, but few relate phase changes to energy transfer from or to the environment.

Many students believe that the temperature of a substance changes continuously as it is heated. They regard phase changes as the result of temperature changes rather than an increase or decrease in the heat content of the material. For these students the idea that a melting or boiling substance absorbs heat without changing temperature is very hard to comprehend. They are also surprised that the temperature of a substance does not increase when it goes through a phase change (e.g., boiling water and the steam produced by the boiling both have a temperature of 100° C).

IV. Laboratory Activities

This section contains suggested laboratory activities. As in previous sections, pages on the left are student pages; pages on the right contain information for instructors.

We believe it is especially important for the student to think about and answer the questions at the end of each activity. The questions require them to apply their knowledge about heat and temperature to explain what they have observed. Many students will benefit from postlab discussion of the questions.

This section contains the following activities:

Heat and Temperature (pages 21-24)

Heat Capacity (pages 25-26)

Demonstration: Heat Transfer Through Radiation (pages 27-28)

The first two activities each require about one hour, depending on the amount of time spent on discussion and the speed at which your students work. The radiation demonstration has no time requirement, but it takes 20-30 minutes to achieve reasonably large changes in temperature.

S-21

Heat and Temperature

Introduction

Do hot objects always contain a lot of heat? Does the temperature of an object indicate how much heat it contains? Does water lose all its heat when it freezes?

Many people would answer "yes" to the above questions. They assume that heat and temperature both refer to the same thing. For physicists, however, heat and temperature are very different concepts. Heat is a form of energy. It is the total amount of kinetic energy of the molecules of a substance. Temperature does not indicate the amount of heat energy contained in an object. Temperature is a useful way to compare the intensity or concentration of heat energy in different objects. Scientists define temperature as the average kinetic energy of the molecules in an object.

Purpose

In this lab, you will investigate the difference between heat and temperature, and identify important variables associated with each.

Materials

2 Electric heating coils
2 250 ml. pyrex beakers
2 Thermometers
1 Timer or watch with second hand

Procedures

1. Put 150 ml. of cold water in each beaker.

2. Measure the temperature of the water in each beaker and record it in the table below. The initial temperature of the water in each beaker should be the same.

3. Immerse a heating coil in each beaker so that it touches the bottom of the beaker. Plug in both heating coils at the same time and start the timer. Use the coil to gently stir the water as it is heated.

4. Measure and record the time required for each beaker to reach 60° C. Unplug the heating coils. (Note: Never remove the heating coils from the water while they are plugged in.)

Beaker	Initial Temperature	Final Temperature	Heating Time
A	____ C	60° C	____sec.
B	____ C	60° C	____sec.

Did the two beakers take about the same amount of time to reach 60° C? If they did not, you may have a problem with your heating coils. Try the experiment again, and check with your laboratory instructor if you still get quite different times.

Commentary

Rationale. This activity is designed to confront students' naive conceptions about the nature of heat and temperature and illustrate the difference between the two concepts.

Steps 1-4 allow the student to become familiar with the use of the heating coils and to verify that they both heat water at the same rate. The heating time can be used as a reference point for the remaining steps.

5. Now put 100 ml. of cold water into Beaker A and 200 ml. of cold water into Beaker B. (The temperature of each sample should be the same.) Record the initial temperature in the table in step 6 below.

   How long do you predict it will take to heat each beaker at 60° C?

   ____ seconds for Beaker A

   ____ seconds for Beaker B

6. Using the same procedures as before, heat each beaker until the water temperature reaches 60° C. Record the heating times below.

Beaker	Amount of Water	Initial Temperature	Final Temperature	Heating Time
A	100 ml	___ C	60° C	____ sec.
B	200 ml	___ C	60° C	____ sec.

7. Were your predictions correct? _____

   How would you explain the difference in heating time for the two beakers?

8. Looking at the table in step 6, which column do you think best indicates the amount of heat absorbed by the water in the two beakers?

   _____

9. In this activity, the temperature change was the same for both beakers. Does that mean that they both absorbed the same amount of heat? Explain your answer.

10. The previous activity involved three important variables:

    1. The amount of substance (mass of volume).

    2. The amount of heat absorbed (indicated by the heating time).

    3. The temperature (or change in temperature).

    Think about the relationships among these three variables. Is there a <u>direct</u> relationship between rate of temperature change and the amount of substance (i.e., adding more water makes the temperature rise faster) or an <u>inverse</u> relationship (i.e., adding more water makes the temperature rise slower)? _____

    Is there a direct or an inverse relationship between temperature change and the amount of <u>heat</u> added? _____

Steps 5-9 illustrate the idea that equal changes in temperature do not indicate that equal quantities of heat are involved. The amount of substance involved is an important variable which must be considered when determining the amount of heat added.

5. Students whose initial predictions are the same for both beakers are clearly confusing heat and temperature. The time predicted for Beaker B should be twice as long as that predicted for Beaker A.

6. In this activity, the initial water temperatures should be the same in both beakers.

7. The students should recognize that the amount of water affected the heating time.

8. The students should recognize that heating time provides the best indicator of the quantity of heat added.

9. The students should realize that the two beakers must have absorbed different amounts of heat because the amount of water in the beaker was different. Students who use only heating time as evidence should be encouraged to think about the reason that the heating time differed.

10. The students should recognize that an inverse relationship exists between temperature change and the amount of substance, and that a direct relationship exists between temperature change and the quantity of heat added.

11. Try using these relationships to predict what would happen in another experiment. What should happen if we add the same amount of heat to 100 ml and 200 ml of cold water?

12. Design an experiment to test your prediction. How can you use your equipment to add the same amount of heat to two beakers, one with 100 ml of water and one with 200 ml?

13. Now do your experiment and record your results in the table below.

Beaker	Amount of Water	Initial Temperature	Final Temperature	Heating Time
A	100 ml	___ C	___ C	____ sec.
B	200 ml	___ C	___ C	____ sec.

Was your prediction correct? _____

14. Consider the three experiments that you have done in this laboratory, summarized in the charts for questions 4, 6, and 13. Answer the questions below for each experiment. (if the beakers were about the same, write "same.")

	Q. 4	Q. 6	Q. 14
a. Which beaker was hotter (i.e., temperature) at the end?	_____	_____	_____
b. Which beaker had more heat added during the experiment?	_____	_____	_____
c. Which beaker had the greatest total heat content (including heat that was in the water before you started) at the end of the experiment?	_____	_____	_____

d. Explain your response for part c.

15. Now let's think about what was happening at a molecular level. What were the heating coils doing to the molecules of water in the beakers?

12. The students should predict that the temperature change for 200 ml of water should be about half as much as for 100 ml. Those who predict that the temperature change should be equal are still confusing heat and temperature.

13. Explanations will vary a little. The key factor in this experiment is that the heating times should be equal for both beakers. Make sure that the students don't choose heating times that cause the water to boil. The initial water temperatures do not have to be equal, it is the change in temperature that is important. The data should show that the heating times are the same, and that the temperature change for Beaker A should be about twice as great as Beaker B.

14. The responses should be as follows:

	Q. 4	Q. 6	Q. 14
Part a:	same	same	A
Part b:	same	B	same
Part c:	same	B	B

This question is a good one to focus on in a postlab discussion. If students are capable of both answering the questions correctly *and* explaining their reasons, then you can feel assured that they have achieved the objectives of this laboratory.

Reasoning for part d: At the beginning of the experiment, the 200 ml beaker contained more heat because it contained more water and the temperatures of both beakers were the same. Because the same amount of heat was added to each beaker, it must still contain more heat at the end of the experiment.

15. The students should recognize that the heating coils were making the water molecules move faster, increasing their kinetic energy.

16. When we say that the water in a beaker is "hot," are we referring to heat or temperature? _____

What does it mean in terms of molecular motion or kinetic energy to say that the water is hot?

Does the temperature depend on the amount of water (i.e., the number of water molecules) in the beaker? _____

17. When we say that the water in a beaker has a high heat content, are we referring to heat or temperature? _____

What does it mean in terms of molecular motion or kinetic energy to say that the water has a high heat content?

Does the heat content depend on the amount of water (i.e., the number of water molecules) in the beaker? _____

16. Temperature. Responses should show that "hot" indicates how fast the molecules are moving or that their average kinetic energy is high. Students should *not* relate "hot" to the amount of water in the beaker.

17. Heat. Responses should focus on the total kinetic energy of all the molecules, and this depends on the amount of water.

    Some students may state that high heat content must also mean high temperature. They probably do not fully understand the difference between *average* kinetic energy and *total* kinetic energy.

Heat Capacity

Introduction

In the last experiment, you learned that heat and temperature are not the same. Heat is a form of energy and is related to temperature and the amount of matter. Different amounts of water could be heated to the same temperature, but more heat energy was required to heat the large mass than the small one. You also learned that temperature could be measured directly, but the amount of heat added to the beaker could not be measured directly. Three important variables were identified: quantity of heat, temperature, and the amount of matter.

In this experiment, you will learn about another important variable. You will investigate the effects of heating different kinds of matter.

Purpose

The purpose of this experiment is to compare the quantities of heat necessary to change the temperature of different types of matter. Scientists refer to this property as the heat capacity of matter. Heat capacity is defined as the quantity of heat energy needed to increase the temperature of a given amount of a substance (usually 1 gm) by one degree.

Materials

2 Electric heating coils
2 250 ml. beakers
1 Timer or watch with second hand
150 ml cooking oil

Procedure

1. Add 150 ml of cooking oil to Beaker A. Measure and record the temperature of the oil on the chart in question 3.

2. Add 150 ml of water to Beaker B. Adjust the temperature of the water until it has the same initial temperature as the oil. (Mix warm and cool water to accomplish this.)

   In the next step, you are going to heat each beaker until its temperature reaches 60° C. Do you think it will require the same quantity of heat (same heating time) for each beaker? Explain.

Commentary

Rationale. The purpose of this activity is to acquaint the students with the concept of heat capacity. Although many of them understand that "some things heat up faster than others," few understand *why* such differences occur.

Steps 1-2.

Student predictions will vary, but most should predict that the oil will require less time to reach 60° C. Some students may explain heat capacity in terms of the materials' reaction to heat (the oil got hot faster, so it has a greater heat capacity) or in terms of the *rate* of temperature increase.

3. Use the heating coils to heat each beaker until the temperature of each material reaches 60° C. Measure and record the heating times on the following chart.

Beaker	Matter	Initial Temperature	Final Temperature	Heating Time
A	150 ml oil	___ C	60° C	___ sec.
B	150 ml water	___ C	60° C	___ sec.

Was your prediction correct?

Which liquid has the greater heat capacity? (which requires more heat to warm it one degree?) _____ Explain.

4. Now let's compare the temperature change for each liquid if equal quantities of heat energy are added to each beaker. What do you predict will happen if we do this?

5. How can you design an experiment in which equal amounts of heat are added to each liquid?

6. Put 150 ml of cooking oil in Beaker A and 150 ml of water in Beaker B. Carry out your experiment and record the data on the chart below.

Beaker	Matter	Initial Temperature	Final Temperature	Temperature Change	Heating Time
A	150 ml oil	___ C	___ C	___ C	___ sec.
B	150 ml water	___ C	___ C	___ C	___ sec.

a. Was your prediction correct? _____

b. Which liquid has the greater heat capacity? _____

c. Do your results agree with those obtained in step 3? _____

7. Use the concept of heat capacity to explain your results.

8. What does it mean in terms of molecular motion or kinetic energy to say that a substance has a high heat capacity? a low heat capacity?

4. The students should predict that the water will change temperature less than the oil.

5. The initial temperature of the oil and water do not need to be equal for this experiment. The most important variable is the heating time, which should be the same for each beaker.

6. The student data should indicate that the oil increased in temperature more than the water. Students who conclude that their results do not agree with the earlier experiment may be thinking that high heat capacity means greater (or faster) temperature change.

7. Responses should refer to the idea that substances with higher heat capacities require more heat to change temperature. Again, some may explain heat capacity in terms of the *rate* of temperature increase.

8. Responses should focus on the idea that the molecules in substances with high heat capacities require more heat to increase their motion (or average kinetic energy) than substance with low heat capacities.

Demonstration: Heat Transfer Through Radiation

There are three different processes by which heat is transferred from one body to another. These processes are conduction, convection, and radiation. This demonstration is designed to help you better understand the process of heat transfer through radiation.

Radiation is a process in which energy in the form of electromagnetic waves is transferred from one place to another. These waves do not require a medium (molecules) in order to transfer their energy, thus they can travel through a vacuum. Light energy traveling from the sun to the earth is an example of radiation in which the waves are visible. The waves used by communication satellites to broadcast television and radio programs also radiate through space and the atmosphere are another example, although the waves themselves are not visible.

When electromagnetic radiation is absorbed by an object, the energy is transformed into kinetic energy of the object's molecules: Heat! This is true for all wavelengths of electromagnetic radiation, including both visible and invisible wavelengths.

Observations of temperatures

	Initial Temp.	Final Temp.	Change in Temp.
White Can			
Black Can			

Questions for Discussion

1. Did the cans absorb energy? Explain in terms of molecules and their motion.

2. Could the energy have been transferred from the molecules in the heat source to the molecules in the cans via conduction?

3. Could the energy have been effectively transferred by convection currents in the space between the heat source and the cans?

Commentary

Rationale. We have found that many students are committed to the misconception that heat is somehow a part of electromagnetic radiation. Students typically refer to "heat being contained in light" or "heat rays traveling from the sun to the earth." These students do not recognize heat and electromagnetic radiation as separate forms of energy.

This demonstration and discussion questions are designed to confront that misconception by eliminating direct heat transfer as a possible explanation for the observed temperature changes. It also illustrates differences in absorption rates of light-colored and dark-colored objects.

The demonstration requires an electromagnetic radiation source such as a heat lamp, two metal containers (one painted black, the other white), and two thermometers. Equal amounts of water (or cooking oil) are placed in each can.

After introducing the demonstration and recording the initial temperatures of the cans, the radiation source is turned on and focused on the cans. Depending on the equipment used, the time required to obtain useful temperature changes will vary. You may wish to introduce the demonstration at the beginning of class, complete other activities, then return to the demonstration and discussion questions.

The following pages include a short introduction, data chart, and a set of discussion questions. These pages can be used to guide the demonstration and discussion, or they can be copied and distributed to the students.

Discussion questions

1. The students should realize that the cans had to absorb energy since their temperature increased. The additional kinetic energy of the molecules must have come from somewhere.

2. The students should realize that heat energy could not have been transfered via conduction since there was no direct contact between objects of different temperatures.

3. The students should realize that convection currents could not transfer the heat energy. A few may think that this is a reasonable possibility, since the air molecules are free to move from the radiation source to the cans. These students probably don't realize that the radiation has very little possibility of interacting with the air molecules. Further, any heated air would rise rather than move horizontally.

4. Were any molecules at all involved in <u>transferring</u> the energy from the source to the cans?

5. Heat is defined as the total kinetic energy of a group of molecules. If no molecules were involved in the transfer of energy, would you conclude that <u>heat</u> was traveled from the heat lamp to the cone? Explain.

6. Heat lamps emit large amounts of infrared radiation. Use this information to explain:

   a) Why the cans became hotter.

   b) Why the black can became warmer than the white can.

7. On sunny winter days, the snow on blacktop roads will melt even though the air temperature is below 0° C (32° F). Explain how the sun helps melt the snow.

4. The students should conclude that molecules were not involved in the energy transfer process.

5. The students should conclude that, although energy was transferred from the radiation source to the containers, it could not have been heat energy since no molecules were involved in the transfer process.

6a. Explanations should refer to energy in the form of radiation traveling to the containers and being *converted* into molecular kinetic energy when the radiation is absorbed by the containers. The key issue is the conversion of radiant energy into heat energy.

6b. The students should conclude that the black can became warmer because it absorbed more of the radiation.

7. The students should realize that the sun emits electromagnetic radiation that travels to the earth and strikes the pavement where it is converted into heat energy. The heat energy is transferred by conduction into the snow, raising its temperature until it melts. The key issues are the conversion of electromagnetic radiation into heat and the transfer of heat from the road to the snow. Some students may describe the snow absorbing the radiation directly. Those who do not understand radiation and energy conversion at all may respond with a cause-effect statement such as "the sun makes it melt," or "the snow melts because the sun shines on it."

V. Problem Sets

The following section contains two problem sets which include questions about heat, temperature, and heat transfer. The questions give students a chance to use newly acquired scientific conceptions to solve problems. Also, you can evaluate how well students have replaced naive conceptions with scientific conceptions.

Suggested Use for Problem Sets

Problem Set 1 contains questions relating primarily to heat and temperature, whereas Problem Set 2 focuses on heat transfer processes. Both problem sets can be done by students independently, then checked by the instructor and/or discussed in class. The problems can also be adapted for use as test questions.

These problems are often difficult for students because they require them to organize their newly acquired knowledge into a coherent scheme. Many students will need to discuss the questions in class after attempting to answer them.

Problem Set 1: Heat and Temperature

1. Three systems of atoms are shown below.

A		B		C	
Atom	Kinetic Energy	Atom	Kinetic Energy	Atom	Kinetic Energy
1	5	1	3	1	3
2	7	2	2	2	4
3	3	3	1	3	2
		4	2	4	7
		5	2		

---

a. Which system contains the most heat (total kinetic energy)?

_____

b. Which system has the highest temperature (average kinetic energy)?

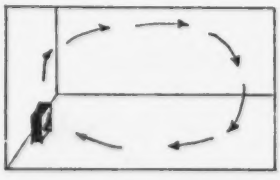
_____

c. Do systems with more molecules automatically contain more heat than systems with fewer molecules? _____ Explain.

2. Beaker X contains water at 15° C. Beaker Y contains water at 30° C. Compare the molecules of water in the two beakers.

3. If a rectangular block of iron is heated from 20° C to 50° C, how will its shape change? Explain in terms of molecules and their motion.

4. The diagram at the right shows a convection current caused by a heater in a room. Why does the heated air rise instead of just moving across the room?



5. Why does heating the top of a jar make it easier to remove a too-tight lid?

Commentary

1. This question addresses the difference between heat and temperature. Students should choose C for Part a, and A for Part b. Part c illustrates the idea that the heat content of a system is not determined by mass alone.

2. This question addresses the meaning of temperature. Complete responses should indicate that the molecules in beaker Y are (a) moving faster, (b) possess greater kinetic energy, and (c) are further apart.

   The students should *not* refer to "hot molecules" or to molecules expanding. Those who do probably do not understand that individual molecules only move faster or slower (gain or lose kinetic energy).

3. This question addresses the effects of heating matter. The students should realize that the molecules move further from one another in all directions, not just in length.

4. This question addresses both the nature of heat and the formation of convection currents. Many students consider "rising" to be a property of heat or heated objects, and never think about the underlying mechanism. They should recognize that heated air is less dense than the cooler air, thus is forced upward as gravity pulls the cooler air downward toward the floor.

5. This question addresses the process of thermal expansion. The students should at least recognize that heating causes the metal to expand, decreasing the friction between the metal and glass. Some students will recognize that the glass also expands, but not as much as the metal.

Problem Set 2: Heat Transfer

What heat transfer is taking place in each of the following situations?

	Situation	Heat is transferred From	To	Mechanism (conduction, convection, radiation)
a.	ice cube in water	_____	_____	a. _____
b.	Sun shining on the Earth	_____	_____	b. _____
c.	The Earth at night	_____	_____	c. _____
d.	refrigerator door left open	_____	_____	d. _____
e.	frying an egg	_____	_____	e. _____
f.	baking a cake	_____	_____	f. _____
g.	touching a hot object	_____	_____	g. _____
h.	standing across the room from a hot fireplace	_____	_____	h. _____

2. Explain what is happening to the molecules of the following:

   a. The ice cube and the water in 1a.

   b. The earth at night in 1c.

   c. The cold air inside the refrigerator in 1d.

Commentary

This set of exercises addresses the processes of conduction, convection, and radiation. Each situation illustrates a form of heat transfer. Some students may identify more than one mechanism for some situations if their analysis is very detailed, however students sho don't understand the differences in the processes will have difficulty identifying any mechanism.

1. Situation	Heat transferred From	To	Mechanism	Comments
a	ice	water	convection	Some may add conduction.
b	sun	earth	radiation	
c	earth	space	radiation	Some may add that the earth warms the atmosphere as well.
d	room	fridge	convection	
e	pan	egg	conduction	
f	oven	cake	convection	Some may add conduction between hot pan and cake.
g	object	finger	conduction	
h	fire-place	person	radiation	

2. This question requires students to explain one example each of conduction, convection, and radiation at the molecular level.